LA-UR-19-32661
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Title: CICE Consortium Progress Report, June 2018 - December 2019

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Intended for: Report

Issued: 2019-12-19

CICE Consortium

Progress Report

June 2018 - December 2019

Overview

The CICE Consortium accomplished a number of major upgrades to our sea ice model code, scripts and testing infrastructure, while strengthening our visibility in the international modeling community. We released CICE versions 6.0.0, 6.0.1, 6.0.2 and 6.1.0, all of which include updated releases of Icepack. Major new capabilities include a floe size distribution, new coupling infrastructure, improvements to all of CICE's dynamics options, a new atmospheric data set for historical simulations, overhauled documentation, and more robust and flexible scripts for running and testing the code. Several key testing processes were automated this year. In addition, the team is actively engaged in planning our first user workshop and tutorial in February 2020.

In addition to overseeing modifications to the Consortium's resources and code releases, management tasks included meeting with and updating the Consortium's Sponsors group in October 2018, prioritizing tasks by mapping them onto potential release targets, and rescuing early CICE releases (version 1 through 3.14) from a disappearing LANL archive.

Based on the Sponsors' recommendation, the Danish Meteorological Institute (DMI) was invited and joined the Consortium, sharing responsibility for the CICE dynamical core with Environment and Climate Change Canada. Two team members moved to LANL from their former institutions to work with E3SM and are continuing their involvement in CICE Consortium activities. One of these, Andrew Roberts, has agreed to serve as the Deputy Lead Coordinator for the Consortium, a position that had never been filled. Partly as a result of his move, the Consortium leadership recommends that the Naval Postgraduate School be replaced with the Polish Institute of Oceanology (IOP) as a formal Consortium Member; the Regional Arctic System Model (RASM) would be acknowledged for its funding support when appropriate. Per the Consortium's governance documents, several of these changes require approval of the Executive Oversight Board or the Sponsors group, which will be convened in early 2020. Dorothy Koch, who led the Sponsors group as a program manager at DOE, moved to a new position at NOAA. While DOE conducts a search for a new program manager, Sally McFarlane is serving in an acting role.

The CICE Consortium team maintains its vitality and cohesiveness through monthly telecons and other meetings scheduled as needed, and through communications via GitHub tools. Team members also strive to maintain the Consortium's visibility in and interactions with the larger

community. This year, our Quality Control (QC) paper was published; the response to reviewer comments led to an updated QC testing procedure. The US Global Change Research Program highlighted the CICE Consortium in its 2018-2019 report, and the Department of Energy published flyers highlighting both Icepack and the CICE Consortium. Articles for the general public appeared in the Santa Fe New Mexican newspaper and at phys.org. We listed the CICE Consortium on GitHub's government research page, instituting a new "International" category of projects. We also continued to grow our Zenodo community by posting additional resources, including new code releases, data and graphics. Our AGU 2018 town hall was well attended by the international modeling community and featured a CICE video in addition to updates from team members on Consortium work. Links to all of these resources are provided in tables below.

A number of improvements planned for the model this year are closely interrelated, and therefore their implementation into the Consortium's repositories is being carefully coordinated. In some cases, team members' other commitments outside the Consortium have led to delays in the original implementation, but we are able to back-fill with other tasks while waiting for some of these major new additions to be ready.

Major improvements for Icepack since June 2018 include

- Improved warning package
- Added support for CMIP6 history output
- New floe size distribution ported from developer's CICE v5 to Consortium's v6
- Improvements to the interface between Icepack and host models

CICE model development highlights

- Improved all three dynamics options
    - Added a vectorized EVP kernel
    - Debugged rEVP
    - Improved EAP efficiency
    - Increased from 120 to 240 dynamics subcycles based on community input
- Improved the landfast-ice parameterization and added bathymetry files for testing
- Improved Quality Control testing
- Added JRA-55 atmospheric forcing
- Added CMIP6 history output

Software engineering upgrades

- Restructured drivers to allow new coupling options
- Automated testing of documentation changes
- Added dynamic array allocation (a major code overhaul including tracer initialization)
- Addressed compiler issues,
- Added namelist checking and flexibility to scripts,
- Refactored code to enable bit-for-bit global sums in log output for different decompositions and processor counts
- Added forcing configuration for HYCOM coupling
- Ported the code to numerous machines

Home page	https://github.com/CICE-Consortium
Resource Index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
CICE repository	https://github.com/CICE-Consortium/CICE
CICE releases with lists of enhancements and bug fixes	https://github.com/CICE-Consortium/CICE/releases
Icepack repository	https://github.com/CICE-Consortium/Icepack
Icepack releases	https://github.com/CICE-Consortium/Icepack/releases
Trunk from subversion repository	https://github.com/CICE-Consortium/CICE-svn-trunk
Archived subversion repository (private, requires permission)	https://github.com/E3SM-Climate/CICE-archive
FTP repository	ftp://ftp.cgd.ucar.edu/archive/Model-Data

2019 Work Plan

The following text updates the status of each of the items we called out in our 2019 Work Plan.

EVP kernels

The new EVP software kernels developed by DMI have been tested and merged into the main CICE repository. These kernels vectorize the data structures and rely on threading (OpenMP) for parallelism, allowing the dynamics to be run without MPI communication during the subcycling, alleviating a major bottleneck for computational efficiency. The EVP kernel development and testing uncovered some issues with OpenMP threading in the code, which is being addressed separately (see below).

Implicit dynamics solver

ECCC is currently adapting an implicit approach for solving the dynamics (momentum and stress) equations, which will provide an alternative to EVP and EAP. It is expected to be ready for Consortium testing and merging into the CICE repository by mid 2020.

C-grid dynamical core

To prevent software conflicts and repetitive work, a number of tasks need to be completed before the C-grid dynamical core is implemented, including bringing CICE version 6 fully into CESM. This requires porting features from the older, B-grid CICE version currently used in CESM into CICE v6 (see below) and implementing the new NUOPC cap for coupling with CESM (also below). NCAR expects to work on the C-grid dynamical core in the first half of 2020, depending on timely completion of these other tasks. Planning for the C-grid dynamical core has begun, with conference calls among team members to discuss critical aspects of the design.

New landfast ice grounding scheme

ECCC is developing this new parameterization, which calculates the seabed stress based on the probability of contact between the ice (based on the thickness distribution) and the seafloor. They are testing it now, have a paper in preparation, and expect it will be merged into the master code in early 2020. The current scheme has also been modified, most notably through the addition of an ocean bathymetry data set suitable for use in our global tests.

Floe size distribution

A major addition to Icepack is a new floe size distribution developed by Lettie Roach (NIWA, New Zealand, now Univ. Washington) and her colleagues. This capability simulates the development and evolution of horizontal floe size due to processes such as lateral and vertical growth and melting, welding of floes under freezing conditions, and floe breakup by waves, and is closely related to the ice thickness distribution. In addition to the Icepack code, we have added several tests in both Icepack and CICE to test this capability in various configurations.

The floe size distribution is a critical simulation capability needed in E3SM for wave-ice interactions and also for a new DOE project, Interdisciplinary Research for Arctic Coastal Environments (InteRFACE). DMI is also interested in it from an operational perspective. We hope to further validate the model based on Danish ice charting resources, during the coming year.

Update Icepack interfaces

Discussions for design changes to the Icepack interfaces have begun, with initial changes included in the CICE v6.1 and Icepack v1.2 releases. A critical element of the planning is incorporating feedback from institutions, including GFDL and DOE/LANL, regarding their experiences incorporating Icepack into their host sea ice models.

GFDL has begun incorporating elements of Icepack into NOAA's model. Because their coupling strategy is much different from the common approach in which the sea ice model acts as a

somewhat independent component, they need to call various physical processes individually, e.g. from the ocean component. Thus far, the ridging parameterization did not require any changes to the Icepack interface, although they do need to map the tracers across formats. Incorporating the mushy thermodynamics did entail some changes to the interface, which will be incorporated into the Consortium repo. We also hope to incorporate an improvement by GFDL to the thermodynamic calculation when melt ponds refreeze and (re)melt.

Work to update Icepack in E3SM is ongoing. There is a discussion about how much infrastructure to include in Icepack's driver; community members would like to have more, e.g. netcdf I/O, to use Icepack alone, while groups pulling Icepack into complex host models prefer to keep it simple.

A postdoc at the Alfred Wegener Institute joined one of our team's conference calls to discuss his experience integrating Icepack into FESOM. He was overall very positive about the process and our tools, and suggested that we clarify which variables passed through the interface are necessary for the sea ice simulation and which are diagnostic. He also requested that we build out Icepack with modern I/O tools.

Icepack interface design	https://docs.google.com/document/d/1zK8vvV3KMQ6O7VBaFdDOr4jm6g3gZn7Z8-sDXdxdN8I/edit#heading=h.hyi7l38u12pu

Mushy thermodynamics

A mushy-layer issue occurs in CESM in regions of very thick and rapidly melting ice in the Canadian Arctic Archipelago, in which thick (10 or more meter) layers of ice completely melt from within the sea ice column. There are two ways of addressing the issue, each of which are research projects that the Consortium recommends be undertaken by model development programs outside of the Consortium. First, the model physics can be altered to stop such unphysically thick ice from appearing, which may involve a new tri-variate state space now being introduced to the sea ice model (floe size, thickness, macro-porosity in ridges). The second approach is to run mushy-layer thermodynamics as a super-parameterization (e.g., with extremely high vertical resolution) within the sea ice component. While these approaches are explored, NCAR developed a work-around that redistributes freshwater runoff into constricted bays, which helps keep the sea ice from getting so thick, and a second redistribution of shortwave radiation in the ice column, which prevents it from concentrating in and melting through thick internal layers.

Port CESM features into CICE v6

The most complex of these new features, CESM's sea ice isotopes code, was ported to CICE v6 and a PR submitted to merge it into the main repository, but the tracers were not being

conserved to the degree expected. We expect this problem to be corrected and the code merged in the near future. NCAR expects porting the other items, such as surface atmospheric stability associated with cold-air outbreaks, flux iterations, and history file precision, to be more straight-forward.

Unified NUOPC cap

Team members have been coordinating as they build the next generation coupler, referred to as a NUOPC cap (NUOPC = The National Unified Operational Prediction Capability). There currently are two efforts, NOAA/NCAR and NRL/DMI, teaming in pairs because the institutions share an ocean model, with DMI in particular building on work by both NRL and NOAA/NCAR. While the couplers themselves are developed using programmatic funds outside the Consortium, how they interface with the Consortium's models and how they will be deposited, stored and maintained in the Consortium's repositories have been designed to work for both efforts. We expect that different model requirements among all of the various host models will require each to have its own, specialized cap, and therefore we changed the CICE driver directory structure to allow this flexibility. The NUOPC cap for CESM has been implemented and merged into the CICE repository, a key step in the development of a C-grid CICE implementation. DMI's NUOPC cap has also been added to the repository.

OpenMP threading

DMI identified several problematic loops in the code and commented them out, pending further debugging. Threading work is lower priority compared with other issues but we will try to address it in 2020, as time allows.

Initialization from observational sea ice data

NRL-Stennis is developing a new pan-Arctic test case in which the sea ice thickness is initialized from observed data. This will provide the first "hook" for data assimilation within the Consortium's repositories and could be useful for Quality Control (QC) testing.

Testing upgrades

This year the team settled on required tests and a testing process for code modifications to be merged into the master repositories, depending on the extent to which the modifications change the answers (QC).

NCAR added a tripole grid and tests; LANL added and improved idealized test cases in a "box" configuration; and NRL-Stennis partly automated the QC testing and improved our "quick-look" analysis capability by adding scripts to create maps of output data. NOAA-supported software engineering work in this realm included additional automation of our cloud-testing capability with

TravisCI, having its test results automatically reported to our Test-Results wiki on GitHub in addition to its standard pass/fail banner.

NRL-Stennis also implemented a new atmospheric forcing data set, JRA-55, for global, 1-degree (gx1) tests. As we gain more experience with it, we expect to transition away from our standard, COREII based forcing data set, whose implementation in CICE for AOMIP has demonstrable problems in how the radiation fields are calculated. The JRA-55 data includes leap days, which enabled us to test that aspect of the time manager and revealed some needed modifications.

Test reports	https://github.com/CICE-Consortium/Test-Results/wiki

Refine release process

This year we completed the first major release of CICE since the Consortium's inception, version 6.0.0, and began to make more frequent code releases, with v6.0.1, v6.0.2 and v6.1.0. Our release philosophy is transitioning to more of an ongoing workflow, releasing the code more frequently rather than delaying releases to capture targeted capabilities. We have not set a particular release frequency, however. A set of modifications is targeted for each release and a project board created to track progress, and the release is executed when enough of the major tasks are complete, considering the number and type of changes and the amount of time that passed since the last release. The process itself has become much more standardized and we continue to refine it.

Release process	https://github.com/CICE-Consortium/About-Us/wiki/Release-Process
Project boards	https://github.com/CICE-Consortium/CICE/projects

Community Support

Documentation and the CICE and Icepack workshop/tutorial

NCAR has taken the lead on organizing a first-ever CICE and Icepack community workshop and tutorial, to be held February 3-5, 2020 in Boulder, CO. They secured funding from NSF to support student and postdoc travel, and Consortium team members are developing the agenda and curriculum for the event. It will be held at NCAR's Mesa Lab, with 400,000 core-hours of high-performance computing support from their facilities (Cheyenne). As of December 5, 2019, both the workshop and the tutorial are full, with 35 registered participants including 14 students/postdocs who applied for travel funding (10 will be funded).

The Consortium's governing documents have been working well. This year, following the lead of CESM, we added a Code of Conduct document, linked below.

Documentation of the code and the Consortium's workflow processes have continued to evolve, most notably through a major overhaul of the CICE model documentation for the v6 release, to reflect Icepack having been moved into its own, independent software repository. The primary location for documentation was moved to readthedocs, and an automated procedure to generate and test changes to the documentation during the standard PR process was implemented. Other documentation changes for both Icepack and CICE support our new tests, and we continue to secure DOI numbers for each release and related resources.

General information	https://github.com/CICE-Consortium/About-Us
Code of Conduct	https://github.com/CICE-Consortium/About-Us/blob/master/Governance.pdf
General information wiki	https://github.com/CICE-Consortium/About-Us/wiki
Resource index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Icepack wiki	https://github.com/CICE-Consortium/Icepack/wiki
Icepack documentation, user guide	https://readthedocs.org/projects/cice-consortium-icepack/
CICE wiki	https://github.com/CICE-Consortium/CICE/wiki
CICE documentation, user guide	https://readthedocs.org/projects/cice-consortium-cice/
Zenodo Community (DOIs)	https://zenodo.org/communities/cice-consortium
Workshop and Tutorial	http://www.cesm.ucar.edu/events/2020/cice-icepack/

Visibility

Our QC paper was published (linked below). The revision process generated questions which led to a revision of our QC tests, making them more robust. USGCRP highlighted the CICE Consortium in its annual report for 2018-2019, Our Changing Planet: The U.S. Global Change Research Program for Fiscal Years 2018-2019. CICE and the Consortium were also highlighted in two general-audience articles for phys.org and the Santa Fe New Mexican newspaper (links below). In addition to these publications, we also increased the visibility of the Consortium through a well-attended AGU town hall, organization of a Zenodo CICE Consortium Community, and international advertising for the upcoming workshop and tutorial. Also, we initiated and are currently the only organization in GitHub's international government community list.

Roberts et al., *Phil. Trans. Royal Soc. A,* 2018	http://doi.org/10.1098/rsta.2017.0344
USGCRP annual report highlight	https://www.globalchange.gov/about/highlights/2019-predicting-arctic-sea-ice-change
Santa Fe New Mexican	https://www.santafenewmexican.com/news/health_and_science/sea-ice-more-than-just-frozen-water/article_3c3eaab2-6574-5500-9ac7-3a7659d5c574.html
phys.org	https://phys.org/news/2018-12-arctic-ice-benefit-polar-industry.html
AGU The Field	https://blogs.agu.org/thefield/2018/12/24/modeling-sea-ice-has-impact-far-beyond-the-poles/
AGU Town Hall	https://agu.confex.com/agu/fm18/meetingapp.cgi/Session/56058
DOE CICE highlight	https://climatemodeling.science.energy.gov/technical-highlights/cice-consortium-model-sea-ice-development
DOE Icepack highlight	https://climatemodeling.science.energy.gov/technical-highlights/icepack-essential-physics-sea-ice-models
E3SM poster	https://acme-climate.atlassian.net/wiki/spaces/CNCL/pages/1036386667/Poster+Submission?preview=/10444804488/1048315297/Hunke_E3SM_poster_2019.pdf (available upon request)
CICE video	https://vimeo.com/306045100
Forum	In transition
Zenodo community	https://zenodo.org/communities/cice-consortium
Github government community	https://government.github.com/community/#research

Plans

The Consortium's task list is constantly changing as tasks are completed and new ones arise, many to address issues submitted by external community members. Critical tasks for code releases are organized into project boards, linked above. Ongoing, longer term tasks include enhancing the metrics and analysis capabilities available with CICE, fully automating the test

suites and documentation, deciding if and how data assimilation capabilities that have been developed could be included in the Consortium's repositories, and incorporating other community enhancements as they become available. Data assimilation was the focus of a team meeting this year, where NCAR, NOAA and NRL team members discussed their various approaches, and NOAA invited one of their data assimilation experts as a guest speaker.

Most Consortium activities involve team members from multiple institutions, overseen by the institution responsible for the relevant Consortium Team but often led by people at other institutions. Ongoing and future work in the table below includes items mentioned above.

Team	**Ongoing effort**	**Lead**	**Future work**	**Lead**
Testing and Analysis	Move to JRA-55 for all reanalysis forced tests	NRL	Institute unit tests where it makes sense	NOAA
	Increase code coverage of test suites	NOAA	Incorporate the satellite emulator developed by Navy/DOE	LANL
CICE dynamical core	Add option for an implicit dynamical solver	ECCC	Implement C-grid option	NCAR
	Add probability based grounding scheme	ECCC	Add iceberg grounding interactions for fast ice	DMI
			Create kernels for EAP similar to EVP	DMI
			Add Mohr-Coulomb rheology	ECCC
Icepack	Complete development of the floe size distribution tests	LANL	Add variational ridging scheme developed by Navy/DOE, including interactions with the ice thickness and floe size distributions	LANL
	Complete port of CESM features into CICE and Icepack	NCAR	Port new snow-on-sea-ice model from E3SM	LANL

	Add option for NCAR mushy workaround	NCAR	Improve radiation scheme using MOSAiC measurements	LANL
Infrastructure	Redesign or update Icepack interfaces to account for needs of DOE's E3SM, GFDL's SIS	NOAA	Redesign the CICE time manager	NOAA
	Improved build system	NOAA	Debug and optimize threading	DMI
	Improve automation of testing, documentation	NOAA, ECCC, NCAR	Create a user-friendly grid generation tool	NRL
Community Support	Workshop/tutorial Feb 3-5, 2020	NCAR		
General	Address issues and user questions as needed			All
	CICE: https://github.com/CICE-Consortium/CICE/issues			
	Icepack: https://github.com/CICE-Consortium/Icepack/issues			

Challenges

The online working environment poses some of the most persistent challenges faced by the Consortium. We use a number of externally developed tools, many of which work well much of the time and make our tasks easier, such as automatic testing of both the code and the documentation through Travis CI. Our GitHub repository has 'webhooks' for readthedocs (where compiled forms of our documentation appear) and zenodo (where we register DOI numbers for our code releases and other resources), which automate transfers of information between these sites. None of these tools are foolproof and when they fail, the reasons can be quite opaque. Similarly, we have tried to incorporate a 'code coverage' tool that indicates which lines of code are not accessed by our many tests, but we have not been able to make this tool work well enough to deploy it for regular use.

We have taken advantage of CESM's online bulletin board at NCAR for questions posed by users outside of the Consortium, to keep these conversations separate from our Consortium tasks on Github. However, users continue to contact Elizabeth directly with their questions, or

sometimes they submit issues on GitHub. We have made the links to the bulletin board more prominent in our documentation and GitHub pages, but the bulletin board remains underutilized. Recently, the Consortium's bulletin board area disappeared due to software changes at NCAR. We are working to reinstate our own forum, which exists as part of but is distinct from CESM's, within the new software framework at NCAR.

Finally, an ongoing discussion relates to how far Icepack should be developed as a stand-alone model. For instance, some users have requested that we add I/O infrastructure using netCDF, which would make the column physics model easier to use as a stand-alone tool, but users who want to incorporate Icepack into their host sea ice and earth system models prefer a slim, clean code. A similar conversation is underway for CICE with respect to incorporating external software packages that, while they provide useful capabilities, would also need to be installed on everyone's computing systems. In both cases, the additional infrastructure and capabilities would increase the maintenance workload for the Consortium.

Major agency contributions since June 2018

Agency/ Institution	**Sponsor, EOB Member**	**Team members**	**Contributions**
DOE/LANL	Sally McFarlane, (Acting) Dave Bader	Elizabeth Hunke Andrew Roberts Nicole Jeffery Matt Turner	Project leadership and reporting (prioritization, planning, and oversight), Icepack updates esp. FSD, "box" tests, documentation overhaul, visibility, code release, Zenodo curation
NSF/NCAR	Anjuli Bamzai and Eric DeWeaver, Jean-Francois Lamarque	David Bailey Alice DuVivier Marika Holland	Community liaison, documentation overhaul and automation, Code of Conduct, ftp, bulletin board, CMIP6 history output, tripole grid and tests, mushy thermo work-around, code release assistance, AGU town hall, visibility, workshop/tutorial planning

DoD/NRL	Dan Eleuterio, Ruth Preller (EOB Chair)	Rick Allard David Hebert	SE support, test design/ implementation, JRA-55 forcing data, plotting tools for analysis, automation, visibility
DoD/NPS	Scott Harper, Wieslaw Maslowski	(None)	Statistical quality control theory/testing procedure, Phil. Trans. A lead author
NOAA/NWS	Hendrik Tolman	Tony Craig Bob Grumbine Brad Johnson Bonnie Brown Mark Olsen	Software engineering (SE), esp. coupling infrastructure, run/build scripts, test reporting, automation, code refactor for bit-for-bit comparisons, NUOPC cap interface design; administrative support, leads all code releases
NOAA/GFDL	Ram Ramaswamy, Hendrik Tolman	Mike Winton	Icepack interfaces
ECCC	Pierre Pellerin	JF Lemieux Philippe Blain Frederic Dupont Amelie Bouchat (intern)	Improved landfast ice parameterization in CICE, bathymetry data, improved run/build scripts
DMI	Kristine Madsen	Till Rasmussen Mads Ribergaard	EVP kernel, dynamics testing, HYCOM forcing configuration, OpenMP threading

Trackable Consortium Output	**Identifier**
Through June 2018	
CICE repository	http://doi.org/10.5281/zenodo.1205674
CICE v6.0.0.alpha release	http://doi.org/10.5281/zenodo.1205675
Icepack repository	http://doi.org/10.5281/zenodo.1213462
Icepack v1.0.0 release	http://doi.org/10.5281/zenodo.1215746
Icepack v1.0.2 release	http://doi.org/10.5281/zenodo.1213463
Roberts et al., *Phil. Trans. Royal Soc. A,* 2018	http://doi.org/10.1098/rsta.2017.0344
Allard et al., EGU Abstract	Geophysical Research Abstracts Vol. 20, EGU2018-9495, 2018
Through December 2019	
CICE v6.0.0 release	http://doi.org/10.5281/zenodo.1893041
CICE v6.0.1 release	http://doi.org/10.5281/zenodo.3351684
CICE v6.0.2 release	http://doi.org/10.5281/zenodo.3516944
CICE v6.1.0 release	http://doi.org/10.5281/zenodo.3568214
Icepack v1.1.0 release	http://doi.org/10.5281/zenodo.1890602
Icepack v1.1.1 release	http://doi.org/10.5281/zenodo.3251032
Icepack v1.1.2 release	http://doi.org/10.5281/zenodo.3516931
Icepack v1.2.0 release	http://doi.org/10.5281/zenodo.3568288